TECHNICAL MEMORANDUMS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 369

TESTS ON AN AIRFOIL WITH TWO SLOTS SUITABLE FOR AN AIRCRAFT OF HIGH PERFORMANCE

Lift, Drag, Rolling and Yawing Moment Measurements

By F. Handley Page

From "Flight," January 28, 1926

Washington
July, 1926

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

TECHNICAL MEMORANDUM NO. 369.

TESTS ON AN AIRFOIL WITH TWO SLOTS SUITABLE FOR AN AIRCRAFT OF HIGH PERFORMANCE.*

(Lift, Drag, Rolling and Yawing Moment Measurements.)

By F. Handley Page.

The results that are described in this article form a complete series of tests on an airfoil fitted with front and rear slots, the rear slot being formed between the portion of the wing aft of the rear spar and the forward portion of the flap. The section on which these tests were carried out is one that is suitable for an airplane of high performance, and is, in the slot closed position, a slight variation of RAF 15, the camber being increased to accommodate rather larger wing spars than are possible with RAF 15 section.

The main characteristics of the unslotted wing are similar to those of RAF 15, namely, a maximum lift coefficient of approximately 0.5 with a fairly low minimum drag, and a reasonable movement of the C.P. Slotted, the lift coefficient is increased to 0.8, and with the rear slot open and the flap inclined at 20° angle of attack, the lift coefficient is increased to 1.

Here, then, are comprised the very desirable characteristics of RAF 15 when the slot is closed, together with a lift

* From "Flight," January 28, 1926.

coefficient of 1 with slot open.

In addition to the data on lift, when the front slot is used differentially to vary the lift on one side or the other of the wings, and so aid lateral control, rolling and yawing moments have also been measured.

The profile of the section is shown in Fig. 1, and the ordinates in Table I.

Table I.

H.P. Airfoil A.1.

(Ordinates given as fractions of the chord.)

Distance from Leading Edge	Height of Upper Surface	Height of Lower Surface
0	0.0143	0.0143
0.01	0.0297	0.008
0.02	0.0385	0.005
0.03	0.0451	0.003
0.04	0.0495	0.002
0.05	0.0539	0.001
0.06	0.0572	0.001
0.08	0.0627	0.000
0.12	0.0693	0.001
0.16	0.0726	0.003
0.22	0.0748	0.006
0.30	0.0737	0.008
0.40	0.0715	0.008
0.50	0.0682	0.006
0.60	0.0616	0.002
0.70	0.0528	0.000
0.80	0.0440	0.001
0.90	0.0319	0.003
0.95	0.0253	0.005
0.98	0.0187	0.006
0.99	0.0165	0.007
1.00	0.0110	0.0110

Table I (Cont.)

Construction of Auxiliary Airfoil.

(Ordinates given as fractions of the chord.)

Distance from Leading Edge	Height to Under Surface	Height to Top Surface
0	0.0143	0.0143
0.01	0.0278	0.0297
0.02	0.0360	0.0385
0.03	0.04275	0.0451
0.04	0.04780	0.0495
0.05	0.0520	0.0539
0.06	0.0560	0.0572
0.0702	0.05975	0.05975

Horizontal thickness at 0 dist. from L.E. = 0.001735.

Chord of auxiliary airfoil as fraction of the chord = 0.0834. Gap of front slot as fraction of chord = 0.025.

Forward extension of auxiliary airfoil for front slot open as fraction of chord = 0.0668.

Leading edge of auxiliary airfoil on chord line.

The opening of the forward slot is effected by moving forward the auxiliary airfoil on links pivoted within the leading edge. With slot closed the airfoil is of standard RAF 15 section. With slot open the chord of the airfoil is increased by the amount which the airfoil moves forward.

Table I (Cont.)

Construction of Rear Slot.

(Ordinates given as fractions of the chord.)

Distance from Leading Edge	Height of Ordinates for Front of Rear Slot
0.643	0
0.660	0.0039
0.666	0.00777
0.674	0.0136
0.680	0.0206
0.687	0.0271
0.694	0.0347
0.701	0.0403
0.708	0.0446
0.715	0.0479
0.722	0.0499
0.729	0.0506
0.735	0.0508

Distance from Leading Edge	Height of Ordinates for Nose of Rear Flap
0.713	0
0.720	0.0264
0.726	0.0361
0.734	0.0415
0.740	0.0444
0.747	0.0462
0.754	0.0471
0.761	0.0472
0.768	0.0466

Gap of rear slot as fraction of the chord, 0.00835.

This section has been tested at Cricklewood in the Handley Page tunnel, both unslotted and slotted; the results for the unslotted section are given in Table II and Fig. 2, so that a direct comparison may be made with the slotted section.

The tests were made in a 4-ft. square tunnel on a 36-in.

span model. Corrections have been made for tunnel restriction to the drag coefficient and angle of attack.

Table II.

H.P. Airfoil A.1. (Unslotted.)

Model - 36 in. by 6 in. Air speed - 44 ft./sec.

Angle of attack	K_l	K_d	$\frac{L}{D}$	C.P. as fraction of chord
0.135	0.092	0.00742	12.4	0.405
2.257	0.175	0.00948	18.5	0.334
4.364	0.248	0.0135	18.4	0.299
6.470	0.320	0.01905	16.8	0.285
8.581	0.396	0.02725	14.5	0.278
10.68	0.463	0.0349	13.25	0.271
12.75	0.51	0.0446	11.4	0.259
14.735	0.50	--	--	--

The section tested with front slot and slotted flap, the flap being set at different angles, gave exceptionally good results. The maximum K_{lc} obtained was 1.0, so that the total increase in lift is 98 per cent.

The expressions K_{lc}, K_{dc} and $C.P._c$ are symbols adopted to show that the coefficients have been calculated on the "slot closed area," and in the case of $C.P._c$ the fractions of the chord are given from the leading edge, when the slot is closed.

These symbols only apply to this type of slot where the auxiliary airfoil is moved in a forward direction to open the slot and backwards to close it.

Table III and Fig. 3 give the results of the section with front slot and slotted flap with different flap angles.

Table III.

H.P. Airfoil A.1.

Model	36 in. by 6.4 in.
Chord, slot closed ...	6.0 in.
Gap of front slot ...	0.15 in.
Gap of rear slot ...	0.05 in.
Air speed	44 ft./sec.

Flap angle 0°

Angle of attack	K_{lc}	K_{dc}	$\frac{L}{D}$	C.P. as fraction of chord
0.092	0.0585	0.0166	3.52	0.557
4.30	0.191	0.0237	8.06	0.325
8.57	0.367	0.0309	11.86	0.281
12.84	0.535	0.0503	10.61	0.270
17.06	0.679	0.0750	9.05	0.264
21.23	0.788	0.1109	7.11	0.253
23.27	0.806	0.1344	6.0	0.258
25.2	0.763	0.1568	4.86	

Flap angle - 10°

0.39	0.249	0.0239	10.4	0.465
4.66	0.421	0.0382	11.0	0.382
8.92	0.585	0.0559	10.48	0.337
13.17	0.748	0.0798	9.37	0.305
15.27	0.810	0.0976	8.30	0.300
17.37	0.875	0.1125	7.77	0.285
19.40	0.890	0.1352	6.57	0.292
21.41	0.897	0.1543	5.80	
23.37	0.874	0.1764	4.95	
25.17	0.846	0.2190	3.86	

Table III (Cont.)

Flap angle - 20°.

Angle of attack	K_{lc}	K_{dc}	$\frac{L}{D}$	C.P. as fraction of chord
0.67	0.428	0.0466	9.20	0.618
4.91	0.590	0.0641	9.21	0.470
9.18	0.751	0.0895	8.38	0.410
13.41	0.898	0.1196	7.51	0.330
15.51	0.965	0.1376	7.01	0.334
17.57	0.999	0.1583	6.31	0.318
19.54	0.983	0.1690	5.22	0.315
21.43	0.970	0.1892	5.11	
23.39	0.942	0.2290	4.11	
25.30	0.885	0.2610	3.39	

From this table it will be seen that the lift coefficient of approximately 1 is obtained at a reasonable angle of attack, namely, $17\frac{1}{2}^{\circ}$. As the angle of attack is practically unaltered from that of a normal airplane no difficulties arise in the use of this section in respect to the attitude of the airplane on alighting. Where the maximum lift is obtained at a very large angle of attack it would be necessary to employ an unduly high landing gear, or to set the wings at an excessive angle of incidence on the fuselage, so that at top speed the airplane would fly with a very high tail.

High lift having been obtained with the section, it is necessary to incorporate in the design full lateral control at this high lift, otherwise, while the results are of academic interest, full advantage could not be taken of them in practice, as the pilot would have to fly at a higher speed in order to

obtain lateral control. There are many ways in which the control can be obtained. One method is to reduce slightly the angle of the flap for lift purposes and use a maximum angle of, say, only 10°, using the further movement of 10° - or a total of 20° - for lateral control purposes, and on the other side pulling up the flap to - 20°.

The rolling moment which is obtained can be estimated approximately from the difference in the lift coefficient of the two sides of the wing under these conditions. On the one side, with an angle of attack of approximately 20°, the maximum lift coefficient is approximately 1. On the other side, with the aileron pulled up to - 20°, the lift coefficient with slot open was 0.54 (the results with the flap at - 20° are of minor importance and have therefore been omitted from this article for the sake of clearness). There is thus a difference in lift coefficient of 0.46, which is available to provide the necessary rolling moment. Similar results were obtained on the same section with front slot closed and the ailerons moving an equal amount, namely, to +20° on one side and -20° on the other, the difference in lift coefficient being approximately 0.3. The rolling moment for the slotted airplane is therefore superior to that of the standard airplane. The yawing moment in the case of the slotted airplane is slightly worse, due to the heavy drag on the ailerons set at +20°.

In this first method of obtaining lateral control, the lift

is slightly increased on one side and considerably decreased on the opposite side.

A second and better method of control is that in which aileron and front airfoil work in conjunction with one another. This method has already been fully explained in various Technical Memoranda issued by the Aeronautical Research Committee. This system of slot control is of a different variety when the main slots are closed to that when the main slots are open. In an unslotted airplane lateral control at and below the stalling speed is provided by opening the forward slot by a downward movement of the aileron, while the slot on the opposite side remains closed with the upward aileron movement.

With the main slots open an upward movement of the aileron closes the forward slot, while the slot on the opposite side remains open.

The difference in lift coefficient on the two sides is now much greater. If the same aileron angles as in the previous case are taken, the lift coefficient with the ailerons at -20° and the slot closed will be 0.4, and with the aileron $+20^{\circ}$ and slot open, the K_1 will be 1. The difference in K_1 is 0.6, or approximately twice that obtained with the ailerons alone. A further great advantage that is obtained is that the yaw is considerably reduced, and by a suitable arrangement of flap angle and slot can be made to act in the direction of the turn.

These figures are taken from a monoplane test.

For a complete biplane, Fig. 4 shows Vector diagrams of rolling moments against yawing moments tested under four conditions:

(1) With no front slot, flap angle 0°, ailerons -20° and +20°.

(2) With front slot open, flap angle 10°, ailerons -5½° and +26°.

(3) With front slot open, flap angle +10°, ailerons -20° and +20°, with a portion of the front slot equal to the span of the aileron closed on the side with the ailerons -20°.

(4) With front slot closed and flap angle 0°, ailerons -20° and +20°, with a portion of the front slot open on the side with the aileron at +20°.

Rolling moments and yawing moments are given in coefficient form and are in relation to body axis. The tests are directly comparative and can be taken as a true indication of the advantages to be gained from "slotted control."

Reviewing these tests, Case No. 1 represents an unslotted biplane with slotted ailerons at ±20°. The results in Fig. 4 show that the rolling moment increases from 4° up to 12°, then diminishes, and the yawing moment attains maximum at 18°. Thereafter there is a diminution in yawing moment accompanied by a slight diminution in rolling moment. This is a distinct improvement on the ordinary type of aircraft without slotted ailerons. This curve is plotted with the points at the differ-

ent angles marked in the center of a circle.

Case No. 2 is shown on the curves with the points enclosed within triangles. Here again the rolling moment even at 24° is considerable, showing the improvement obtained by using slotted ailerons, the front slot in this case being open the whole way along the span.

Case No. 3 is that of a slotted wing airplane in which the slotted ailerons are used in conjunction with the forward airfoil. The results are shown on the curve in which the points are marked by crosses. It will be observed that the yawing moment even at small angles is less than that in the other cases, and that from 16° it becomes rapidly negative, assisting the airplane in the direction of the turn. With increasing angle also the rolling moment is increased, the rolling moment at 22° being nearly 0.08 against a rolling moment of approximately 0.045 at 0°.

Case No. 4 shows a similar result with front slot closed, the results being somewhat similar to Case 3. The points are indicated on the curves in squares. It will be seen that the rolling moment remains practically stationary, although the yaw at 4° has vanished.

In comparing these different cases, a point of particular interest is the improvement in control of the slotted wing airplane over the standard type when both are fitted with slot and aileron working in conjunction with one another.

The result of the use of this section for the design of an aircraft can readily be seen. Unslotted, the section has a lift coefficient of 0.51 at 12-3/4°; slotted, the maximum lift coefficient is 1 at an angle of 17½°. For the same landing speed, therefore, a slotted wing airplane with this section could have double the loading of the unslotted type. Alternatively, with the same loading the landing speed would be reduced approximately 70 per cent. Most important of all is the great increase in lateral control at the stalling speed. Attention is particularly drawn to Case No. 3, plotted on Fig. 4, in which a very big yawing moment helping the turn is obtained by the use of the slot and aileron control.

Tests on the full scale with this section will shortly be carried out. Tests both for lift coefficient and rolling moments on a completely slotted airplane with a loading of between 12 and 13 lb./sq.ft. with a slightly different section have given confirmatory results on the values of the lift as well as rolling and yawing moments. The mechanical details present no difficulties in construction. The forward airfoil is made out of a single duralumin plate carried on links from the front spar. Closed, the airfoil rests against the leading edge and the section is a standard unslotted one. It is hoped that photographs and details of this may be published in a later article.

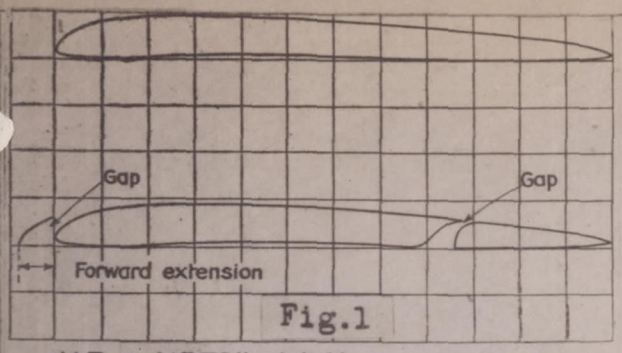


Fig.1

H.P. AIRFOIL. A.I. Unslotted and Slotted.

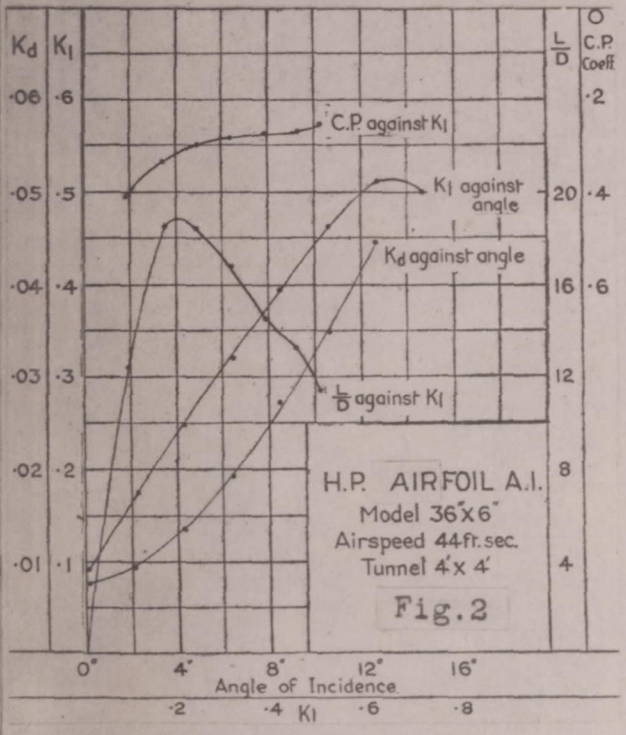


Fig.2

H.P. AIRFOIL. A.I. WITH FRONT SLOT & SLOTTED FLAP.
Model 36" span, Chord Slot open 6·4 Slot closed 6"
Airspeed 44ft. sec. Coefficients calculated on the slot closed area
Tunnel 4'x4'. ○ Flap angle 0°, ● Flap angle +10°, X Flap angle +20°

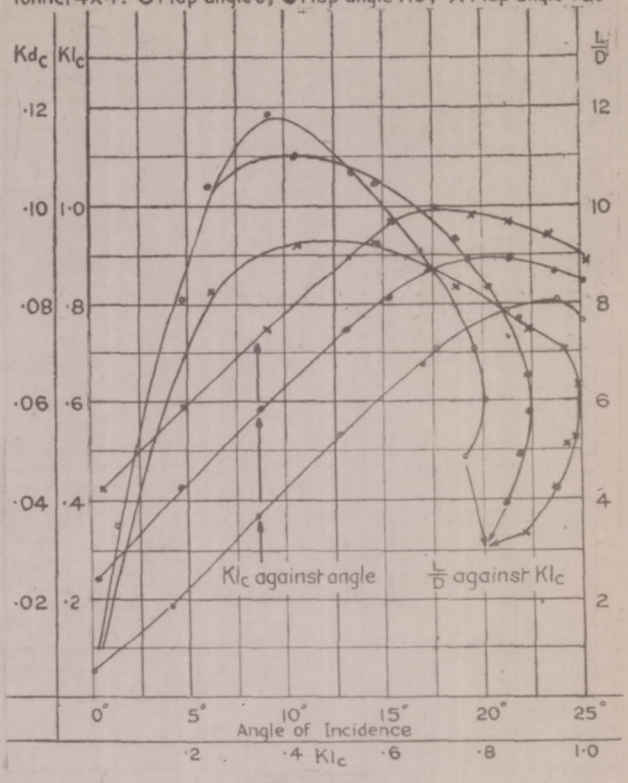


Fig.3

1/16 SCALE MODEL BIPLANE, WITH FRONT SLOT & SLOTTED FLAP. AIRSPEED 44 FT.SEC., TUNNEL 4'x4'

X Front slot open, Flap angle +10°, Port Aileron −20° Port control slot closed, Strbd. Aileron +20° Strbd control slot open
△ " " " " " +10°, " " −5½° " " " open, " " +26° " " " "
□ " " closed, " " 0°, " " −20° " " " closed, " " +20° " " " "
○ " " " " " 0°, " " −20° " " " " " " +20° " " " closed

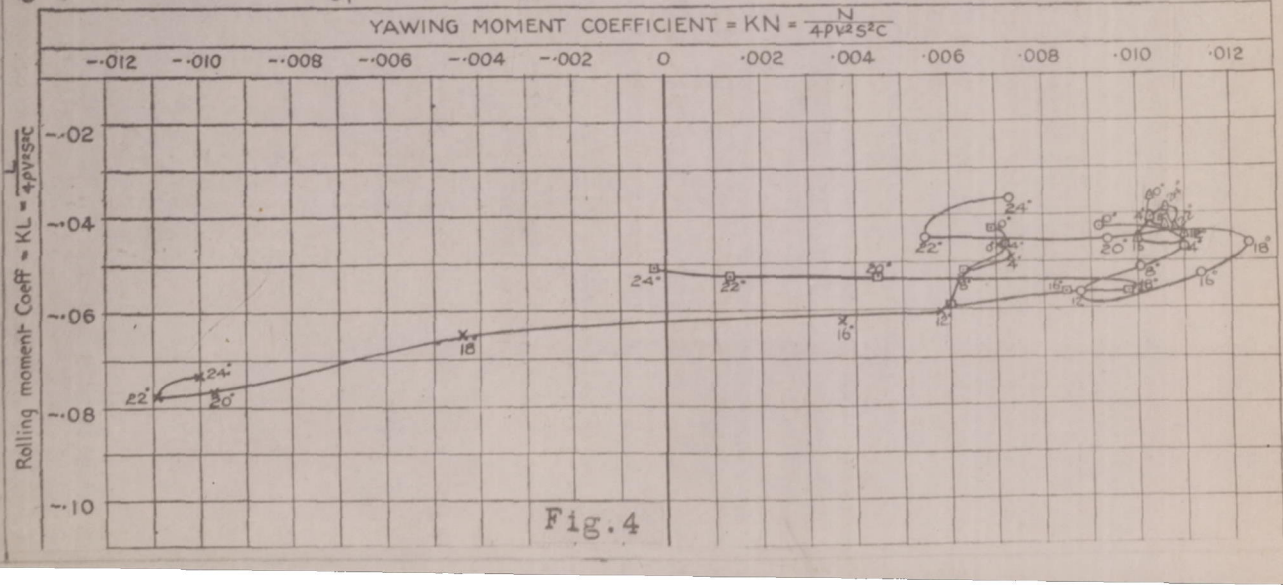


Fig.4